Predictability of Particle Trajectories in the Ocean

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LONG-TERM GOALS

The long term goal of this project is to determine optimal sampling strategies for drifting buoys, in order to enhance prediction of particle motion in the ocean, with potential applications to ecological, search and rescue, the floating mine problems, and design of observing systems.

OBJECTIVES

The specific scientific objective of the work done has been to determine the effectiveness of using in-situ Lagrangian measurements and data assimilation techniques in improving the prediction of particle trajectories.

APPROACH

The work is based primarily on simple probabilistic models of particle motion and data assimilation strategies. It also involves the use of ocean general circulation models and processing of oceanic data.

WORK COMPLETED

The primary accomplishments during this grant period are as follows:

1) A comprehensive testing and validation of a method, which relies on assimilation of Lagrangian data into Lagrangian particle models in order to estimate the velocity field in the vicinity of buoy trajectories and to address the problem of prediction of Lagrangian trajectories have been completed, leading to the publication of 3 papers (Ozgokmen et al., 2000a; Castellari et al., 2001; Ozgokmen et al., 2001).

2) A new algorithm is developed based on the motion of the center of mass of a drifter cluster. This method is tested using stochastic flow simulations and real oceanic drifters. This study is submitted for publication (Piterbarg and Ozgokmen, 2001).

3) The impact of in-situ wind forcing on the reconstruction of drifter trajectories is investigated. This manuscript is submitted for publication (Paldor et al., 2001).

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14. ABSTRACT
The long term goal of this project is to determine optimal sampling strategies for drifting buoys, in order to enhance prediction of particle motion in the ocean, with potential applications to ecological, search and rescue, the floating mine problems, and design of observing systems.

15. SUBJECT TERMS

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4) The PIs of this project organized a scientific meeting called "Lagrangian Analysis and Predictability of Coastal and Oceanic Dynamics - LAPCOD" in Italy in 2000 (http://www.rsmas.miami.edu/LAPCOD). The purpose of the LAPCOD meeting was to conduct a review of Lagrangian data, present new results on nonlinear aspects of Lagrangian dynamics, and to accelerate future development in predictability and multi-disciplinary aspects, by bringing together different research communities. Workshop participants, totaling some 75 scientists, included experimentalists and theoreticians involved in data analysis and model development, biologists and ecologists using Lagrangian instruments and approaches. A review paper summarizing this workshop is submitted for publication (Mariano et al., 2001).

RESULTS

1) The assimilation method has been initially developed using synthetic drifters released in the oceanic flow field generated by an OGCM (Ozgokmen et al., 2000a) and then applied to real surface drifters in the Adriatic Sea (Castellari et al., 2001) and WOCE drifter clusters in the Tropical Pacific Ocean (Ozgokmen et al., 2001). Most of the work for these studies was essentially performed during previous grant periods, and it is now fully complete with the publication of 3 papers.

2) Previous predictability studies, in particular results from Ozgokmen et al. (2001), indicated that when drifters are released in tight clusters, i.e. when the cluster diameter is much smaller than the radius of deformation, there is a period during which the location of the center of mass of the cluster, a simple method, performs as well as the complex assimilation algorithm. Since this initial period of a few days is of importance in some practical applications (e.g., search and rescue missions) a new method was developed for prediction of a Lagrangian particle position in a stochastic flow given observations of other particles (Piterbarg and Ozgokmen, 2001). The algorithm is based on linearization of the motion equations and appears to be efficient for an initial tight cluster and small prediction time. A theoretical error analysis is given for the Brownian flow and a stochastic flow with memory. The asymptotic formulae are compared with simulation results to establish their applicability limits. Monte-Carlo simulations are carried out to compare the new algorithm with two others: the center of mass prediction and the Kalman filter method. The algorithm is also tested on real data in the Tropical Pacific.

Two interesting results from this study with implications for optimal deployment of drifters are shown in Figure 1. The prediction error as a function of the location of the predictor launched within a cluster of 6 predictants forming an hexagon of radius 50 km is shown in the upper panel of Figure 1. This diagram indicates that the optimal location is not the center of the cluster, as one would intuitively anticipate, but off center. The implications of this result are now being pursued in a separate investigation. The lower panel in Figure 1 shows the prediction error vs time as a function of the number of predictors calculated using real oceanic drifters. When the number of predictors is equal to 3, a drastic reduction of prediction accuracy takes place, which is found to be independent of the combination of chosen predictors in this cluster. Otherwise, the prediction accuracy gradually decreases as the number of predictors is decreased from 6 to 4, but the accuracy of the method using 4 to 6 predictors remains essentially constant for prediction periods less than the Lagrangian decorrelation time scale of 3 days.

This new method has significant advantages over the Kalman filtering technique for short-term prediction: (i) the method does not require any parameters, (ii) calculation and processing of large data sets, such as climatological flow field and associated subgrid scale interpolation, are not needed, (iii) initial turbulent velocity, a difficult quantity to know in practical applications, is not needed, and (iv) the method is not based on the integration of velocity field to estimate particle position, which necessarily leads to accumulation of velocity errors as errors of particle position.

3) Given that for a variety of important practical applications, such as search and rescue missions, and dispersion of pollutants, the object of interest is near or at the surface of the ocean, it is inevitable that the wind stress plays an important, if not dominant, role in the dynamics of the object's motion. To address this issue, a hybrid Lagrangian-Eulerian model for calculating the trajectories of surface particles in the ocean is developed. In this model, the particle's velocity is calculated by integrating the acceleration due to the forces that are known to act at the ocean's surface: the wind stress, the Coriolis force and (Rayleigh) friction. The position is calculated by advecting the drifter along with the climatological surface (Eulerian) current in the region.

This method has been tested using 5 clusters of WOCE drifters, totaling 49 drifters, launched in the Pacific Ocean, and the wind data taken from the US Navy Operational Global Atmospheric Prediction System (NOGAPS). The improvement of the prediction error with respect to advection using climatology as a function of model parameters, gamma - the drag coefficient, and alpha - the fraction of particle velocity in the drifter's advection, is shown in Figure 2. This figure indicates that not only is the prediction accuracy improved by a factor of 4 using this method, but also this improvement is robust with respect to changes in the model parameters. However, the optimal model parameters calculated by averaging over the entire data set yield a more modest improvement.

Given the real time availability of wind stress data and the existence of on-line atlases of surface ocean currents, the model provides a practical tool for forecasting of the trajectories of surface drifters.

IMPACT/APPLICATIONS

The investigation of the predictability of particle motion is an important area of study, with a number of potential practical applications at very different scales, including searching for persons or valuable objects lost at sea, tracking floating mines, ecological problems such as the spreading of pollutants or fish larvae, and design of observing systems.

TRANSITIONS

Optimal sampling strategies are being developed with L.I.Piterbarg (University of Southern California). Also, we will collaborate with Dr. Piterbarg on optimal path or navigation problem.

RELATED PROJECTS

Lagrangian turbulence and transport in semi-enclosed basins and coastal regions. PIs: A. Griffa, T.M. Ozgokmen.

Statistical Problems in Ocean Modeling and Prediction. PI: L.I. Piterbarg.

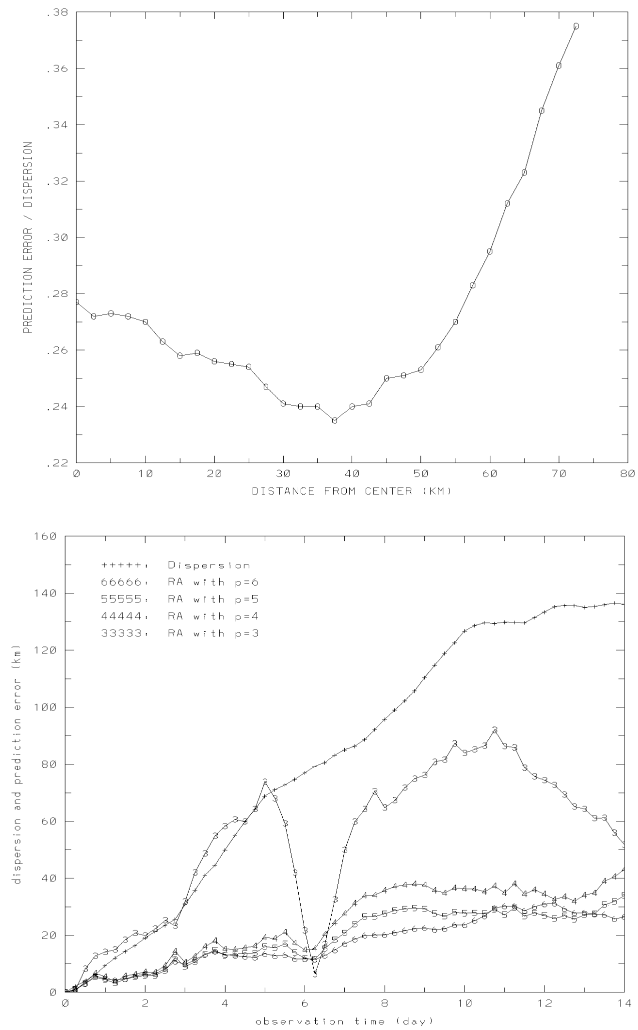

Figure 1: (Upper panel) Relative error as a function of the predictant position. Note that the minimum error is obtained off the center of the drifter cluster. (Lower panel) Prediction error as a function of the number of predictors. Note that the prediction error is not sensitive to the number of predictors for p>3 and for observation periods less than the Lagrangian time scale of 3 days.

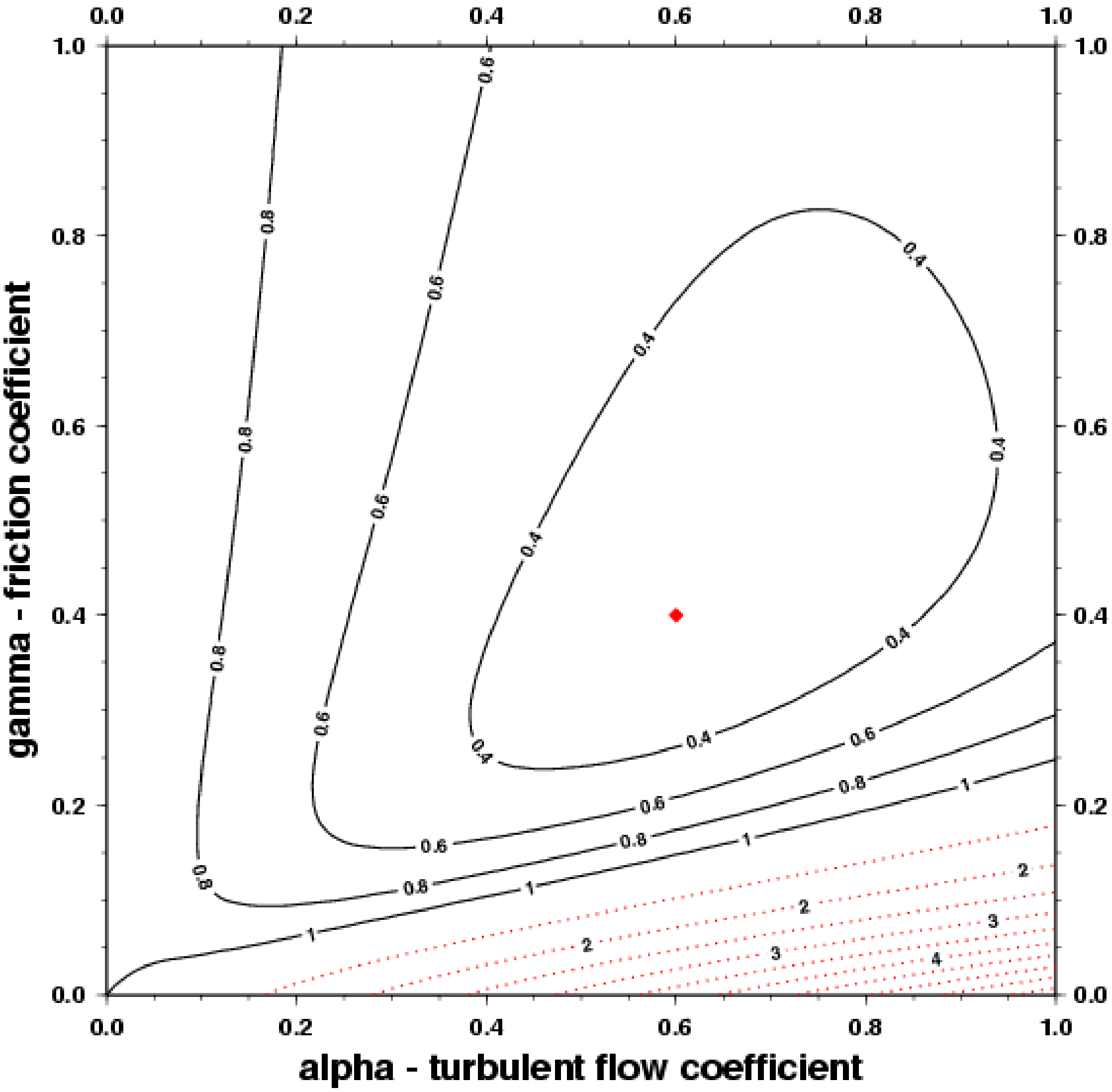

Figure 2: Sensitivity of the relative error, prediction error scaled by dispersion, to the model parameters for one of the drifter clusters in the Pacific Ocean. Note that the minimum error is robust with respect to variations in model parameters, alpha – turbulent flow coefficient and gamma - friction coefficient.

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